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Reduction of harmful emissions from a diesel engine fueled by kapok methyl ester using combined coating and SNCR technology

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ABSTRACT

This research work has been formulated to reduce the stinging effect of NO_X emission on atmospheric environment from a coated diesel engine fueled by biodiesel. As such, in the current study, we attempted to harness the renewable source of energy from in-edible kapok oil, which is normally under-utilized despite being a viable feedstock for biodiesel synthesis. Notably, steam treatment process followed by crushing of the kapok seeds in a mechanical expeller was done to extract large quantities of kapok oil for the application of diesel engine, which is quite distinct of a method adopted herein. The conventional trans-esterification process was availed to synthesize KME (kapok methyl ester) and the physical and thermal properties of it were estimated by ASTM standard methods. Subsequently, two blends of KME with diesel such as B25 (KME – 25% and diesel – 75%) and B50 (KME – 50% and diesel – 50%) were prepared and tested in a single cylinder diesel engine with thermal barrier coating. To help realize the coating process, PSZ (partially stabilized zirconia), a pertinent coating material in respect of its poor thermal conductivity and better durability, has been chosen as the coating material to be applied on engine components by plasma spray coating technique. As an outcome of the coating study, B50 was found to show improved BTE (brake thermal efficiency) than that in an uncoated engine, with notable decrease in major emissions such as HC (hydrocarbon), CO (carbon monoxide) and smoke. However, due to reduction in heat losses and increase in in-cylinder temperature, the NO_X (oxides of nitrogen) emission was expected to be increased in a coated diesel engine. Therefore, in order to reduce the NO_X emission, urea based SNCR system was incorporated in the exhaust pipe and by which, NO_X emission was reduced.

1. Introduction

The depleting crude oil reserves and its implication of surge in petroleum fuel prices have impelled many researchers to indulge in utilizing renewable and biodegradable fuel, biodiesel, in diesel engine [1]. When operating biodiesel in a diesel engine, due to the presence of inherent oxygen within it, emission such as CO (carbon monoxide), HC (hydro carbon) and smoke were reported to be lower [2,3], tending to make the environment greener. Despite many advantages, biodiesel possesses distinct fuel properties like higher viscosity and lower calorific value, which does have a negative effect on combustion and performance of the engine [4,5]. Since the conventional diesel engine is standardized for the use of petroleum diesel, the use of biodiesel demands some modifications with the engine design or operating parameters. In such a back drop, ever since the discovery of biodiesel, researchers are keen to optimize the engine operating parameters such as fuel injection timing, injection pressure and valve timing so as to adapt biodiesel effectively in a diesel engine [6,7]. In addition, some researchers have conceded to modify the engine design either by increasing the engine compression ratio or by coating the engine components with insulating materials [8,9]. Both these approaches were attempted by researchers to increase the engine performance and combustion when fueled by biodiesel.

Among the various engine modification techniques, TBC (thermal barrier coating) of engine components has attracted the attention of many researchers. The notion behind this technique is to reduce the heat losses from the engine by coating the engine components with materials having poor thermal conductivity, so as to facilitate the conversion of accumulated heat into useful piston work. In a recent experimental investigation, Taymaz et al. [9], coated the combustion chamber surfaces, cylinder head, valves and piston crown faces with ceramic materials and demonstrated an improvement in BTE (brake thermal efficiency) and reduction in BSFC (brake specific fuel consumption), when using diesel fuel. With the emergence of biodiesel as an effective replacement of diesel, studies on testing the performance of a coated diesel engine using biodiesel have also been conducted by many researchers. Recently, Hazar [10], in an attempt to examine the effect of TBC on

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engine performance and emission, when using canola biodiesel, reported an increase in BP (brake power), and decrease in BSFC as well as exhaust gas emissions such as HC, CO and smoke. However, due to ceramic coating, the in-cylinder temperature was noticed to be increased and this has had a negative impact of increased NO_X (oxides of nitrogen) emission. In a similar note, Hazar [11], when using cotton methyl ester in a diesel engine coated with molybdenum, reported increased NO_X emission despite the improvement in engine performance. However, the other emissions such as CO and smoke were found to be reduced due to the promotion in combustion, favoured by higher in-cylinder temperature and presence of inbuilt oxygen within biodiesel. In another study, MohamedMusthafa et al. [12], as a new attempt, coated the diesel engine components using fly ash and investigated its performance and emission characteristics using methyl esters of pongamia and rice bran oil. The outcome of their study was found to be in concurrent with the past studies, reporting an improved performance at the expense of higher NO_X emission. Subsequently, many researchers, who have investigated the characteristics of a coated diesel engine using various vegetable oils such as waste corn oil and sunflower oil [13,14], also observed an increased NO_X emission because of the increased in-cylinder temperature and presence of surplus oxygen. The detailed summary on the application of diesel engine coated by various insulating materials, when using biodiesel and vegetable oils, has been listed in Table 1. From the summary, it is clearly evident that though the intended objective of improved performance has been met after coating the engine components, the limitation of increased NO_X emission still persists for various biodiesel and vegetable oils. Thus far, no study has been initiated to curtail the NO_X emission from a coated diesel engine fueled by biodiesel, though the other emissions such as CO, HC and smoke were found to lower. Regardless of the presence of various NO_X reduction techniques for a diesel engine such as optimization of injection timing, EGR (exhaust gas recirculation), SCR (selective catalytic reduction) and addition of NO_X reduction additives [15–18], required attention has not been paid to simultaneously improve the performance and reduce the NO_X emission from a coated engine.

From the above discussion, it is evident that there exists an appeal to reduce NO_X emission from a coated diesel engine fueled by biodiesel. Though the other emissions such as HC, CO and smoke, and performance of the engine were reported to have been improved with the coated engine, still no measures have been taken to reduce NO_X emission. Therefore, this research work has been framed to reduce NO_X emission by implementing a urea based SNCR (selective noncatalytic reduction) system in the exhaust pipe of a coated diesel engine, fueled by a biodiesel. After contemplating on the existence of various biodiesel, it was understood that operation of KME (kapok methyl ester or kapok biodiesel) in diesel engine has not been optimized and studied extensively, despite being an in-edible and underutilized resource [19]. Therefore, herein, we endeavor to prepare biodiesel from kapok oil and optimize its use in a diesel engine by means of the combined coating and SNCR technology. Considering that design modifications would empower using higher blends of biodiesel [20], contrary to the reported adaptation of 20% biodiesel in an unmodified engine [2], herein we have used KME up to 50% with diesel (B25 and B50) in a coated diesel engine with SNCR. Finally, the engine characteristics for the reported blends in a coated engine with SNCR and unmodified engine are analyzed and compared.

2. Materials and methods

2.1. Feedstock for biodiesel synthesis

The feedstock for synthesizing kapok biodiesel is an in-edible source of oil extracted from the seeds of kapok tree, also known as silk cotton tree. Demirbas [2], in his review on progress and recent trends in biodiesel, has pronounced kapok oil as indispensable and economical source for biodiesel production, when compared to other in-edible oils. Thus far, kapok oil is reported to have been extracted by Soxhlet extraction method using n-heptane as solvent [21,22]; however, this study has attributed to extract kapok oil by steam treatment process followed by mechanical crushing. The outline of how the kapok seeds are processed and oil is extracted from them has been depicted in Fig. 1. Firstly, the seeds are preprocessed and fed into a reactor of large capacity to hold bulk volume of kapok seeds. After which, steam from a separate line is allowed to be passed in so as to help separate some fraction of raw oil. Finally, the seeds, which are prone to preprocessing and steam treatment, are crushed in a mechanical expeller to extract the required quantity of kapok oil. For application like diesel engine, this method of oil extraction is reasonable, as it admits bulk extraction of oil in a single trail and makes the method economical. Further, this method is believed to enhance the recovery of oil than other methods and would help improve the properties of the extracted oil. The physical and thermal properties of the oil, as

Table 1
Summary of research work on coated diesel engine fueled by vegetable oil/methyl esters.

Year	Research group	Type of fuel	Coating material	Performance	Emission
2008	Hasimoglu et al. [30]	Sunflower oil methyl ester	Y_2O_3 ZrO_2 – 0.35 mm NiCrAl – 0.15 mm	BTE – ↑ BSFC – ↓	–
2009	Hazar [10]	Canola oil methyl ester	Cylinder head, valves – MgO ZrO_2 Piston – ZrO_2	BP – ↑ SFC – ↓	CO – ↓ Smoke – ↓ NO_X – ↑
2010	Hazar [11]	Cotton seed oil methyl ester	Molybdenum – 0.25 mm NiAl – 0.05 mm	BTE – ↑	CO – ↓ Smoke – ↓ NO_X – ↑
2011	MohamedMusthafa et al. [12]	Methyl ester of Pongamia and Rice bran oil	Fly ash	BSFC – ↓ BP – ↑ BTE – ↑	Smoke – ↓ HC – ↓ NO_X – ↑
2012	Iscan et al. [13]	Waste corn oil	ZrO_2	BP – ↑ Torque – ↑ BSFC – ↓	CO – ↓ Smoke – ↓ HC – ↓ NO_X – ↑
2013	Aydin [14]	Pure cotton seed oil and sunflower oil	ZrO_2	BSFC – ↓ BP – ↑ BTE – ↑	Smoke – ↓ CO – ↓ HC – ↓ NO_X – ↑

↑ – increased, ↓ – decreased when compared to uncoated engine.

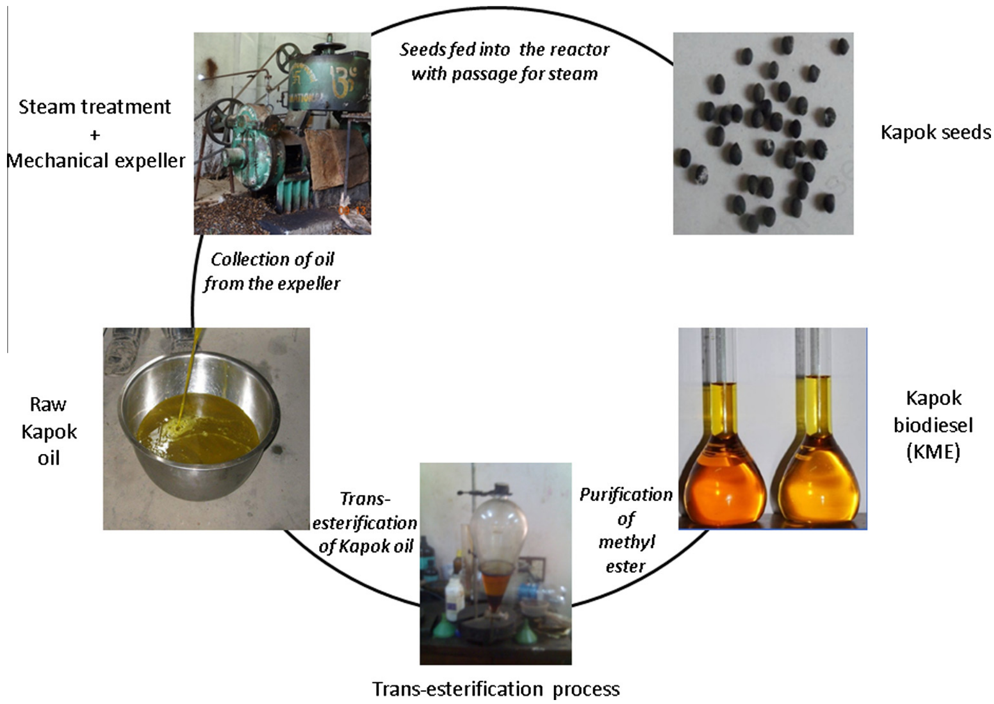

Fig. 1. Kapok oil extraction and production of KME (kapok methyl ester).

Table 2
Properties of kapok oil, kapok methyl ester (KME) and diesel.

Property	Kapok oil	KME	Diesel
Density (kg/m^3)	923.2	875	822
Kinematic viscosity (m^2/s)	31.2 * 10^{-6}	5.4 * 10^{-6}	3.6 * 10^{-6}
Flash point (°C)	170	156	74
Pour point (°C)	−10	−8	−23
Cloud point (°C)	−6	−3	–
Gross calorific value (kJ/kg)	39,086	36,292	42,700
Sulfur content (%)	Less than 0.005	Less than 0.05	Less than 0.005
Calculated cetane index	38	54	50

evaluated by ASTM (American Society for Testing and Materials) standard methods, have been shown in Table 2. The fuel properties reveal that the raw kapok oil has higher viscosity and boiling point, which does not support its direct use in diesel engine. Therefore, it is essential to trans-esterify the extracted kapok oil in order to reduce its viscosity, and bring it to the permissible biodiesel standard so as to make it feasible for diesel engine operation.

2.2. Trans-esterification of kapok oil

The process of trans-esterification to synthesize biodiesel entails an alcohol and catalyst wherein, the tri-glycerides with larger molecules are broken into smaller compounds, esters. As such, in the current study, the extracted kapok oil was trans-esterified using KOH (potassium hydroxide) as catalyst and methanol as solvent to produce KME. For synthesizing 1 l of KME, 200 ml of methanol and 10 g of KOH were found to be required. After the trans-esterification process, the formed glycerol has been drained out and the left out methyl ester is washed with distilled water to remove the impurities and the remaining glycerol. Subsequently, the biodiesel is heated up to 100 °C to remove the last traces of water. Finally, the fuel properties of produced biodiesel (KME) were identified by ASTM standard methods and are shown in Table 2. It is worthwhile to note that after the trans-esterification process, all the properties of KME were found to be in compliance with biodiesel standard. For the current experimental investigation, two probable blends, B25 and B50, were chosen to be tested in the coated engine.

2.3. Composition of KME

It is a well-known fact that biodiesel are methyl esters of fatty acids and therefore, typical composition of a biodiesel, synthesized from vegetable oils, ought to possess long chain methyl esters. The composition of KME was tested in gas chromatography–mass spectrometry (GC–MS) with the column specification of 200 °C operating temperature, 2 °C/min ramp rate, 2 μl/min flow rate and 80:1 split ratio. Notably, the major constituents of KME were identified to be methyl esters of linoleic acid, oleic acid and palmitic acid. The typical composition of KME is shown in Table 3 and after analyzing the fatty acid composition, the presence of unsaturated hydrocarbons with oxygen in their structure is perceivable.

3. Experimental test engine and instrumentation

The test engine used in the current study is a stationary single cylinder diesel engine, used mainly for agricultural and marine application. The engine is coupled with a water cooled eddy current dynamometer and while testing, various loads such as 20%, 40%, 60%, 80% and 100% were applied to the engine by adjusting the current supplied to the dynamometer. The arrangement of the engine set up and all other equipment has been depicted in Fig. 2, and the engine specifications are listed in Table 4.

The fuel supplied to the engine was measured manually using a burette and stopwatch, and the air flow rate of the engine was measured using an orifice meter, fitted in the intake air supply system. Measurement of combustion chamber pressure was obtained by installing an AVL pressure transducer and was recorded using AVL 619 Indi meter hardware and Indwin software version 2.2. Exhaust emissions such as HC, CO, NO_X and O_2 (oxygen) were measured using a NDIR (non-dispersive infrared) AVL-444 digas analyzer. The exhaust sample to be evaluated was passed through a cold trap (moisture separator) and filter element to prevent

Table 3
Composition of KME.

Fatty acid methyl ester	Composition (%)
Palmitic acid (C16:0)	21.2
Stearic acid (C18:0)	4.14
Oleic acid (C18:1)	23.55
Linoleic acid (C18:2)	37.4
Linolenic acid (C18:3)	1.5

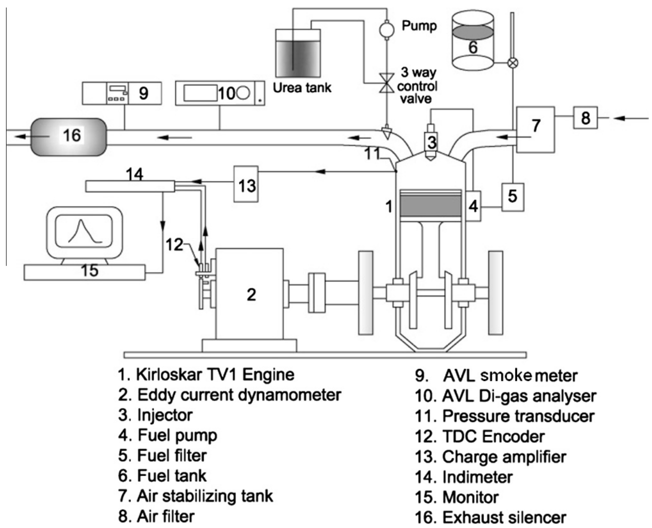

Fig. 2. Schematic diagram of the experimental setup.

Table 4
Engine specification.

Type	Four stroke, Kirloskar make, compression ignition, direct injection, constant speed, vertical, water cooled
No of cylinders	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1
Rated power	5.2 kW
Rated speed	1500 rpm
Dynamometer	Eddy current
Start of injection	23° BTDC
Injection pressure	220 bar
Type of injection	Mechanical pump-nozzle injection
No of nozzle holes	3

Table 5
List of measurement uncertainty.

Measurement	Uncertainty (%)
Load	±0.2
Speed	±0.1
Burette fuel measurement	±1
Time	±0.2
Manometer	±1
CO	±0.2
HC	±0.1
NO_X	±0.2
Smoke	±1
Pressure pickup	±0.1
Crank angle encoder	±0.2

water vapor and particulates entering into the analyzer. Typically, HC and NO_X were measured in ppm (parts per million), and CO and O_2 emissions were measured in terms of percentage volume. Smoke level was measured in HSU (hatridge smoke unit) using a standard AVL437C smoke meter. Each and every measurements pertaining to the investigation of B25 and B50 were noted after the engine has attained steady state condition. Further, all the measurements were noted at ambient atmospheric conditions and repeated for three times so as to ensure the accuracy of the measured values. Moreover, before commencing the experimental investigation with B25 and B50, the engine is made to run with diesel for 30 min to attain warm-up condition, which is ensured by the temperature of the cooling water. The total uncertainty of the experiment, calculated from the uncertainties of various instruments used in the present study as listed in Table 5, was found to be ±2.26% based on the method of propagation of errors as proposed by Holman [23].

3.1. Coating process

The engine components such as top surface of the piston, bottom face of the valves and the cylinder head portion associated with the combustion chamber were coated using PSZ. Plasma spray coating technique has been employed to coat the engine components meticulously; the photographs of the coated engine components are depicted in Fig. 3. Prior to coating, the components are grit blasted so as to attain a surface roughness (Ra) value of 4, after which, the surfaces are cleaned using ethylene glycol. When the components are dried, PSZ is sprayed over cleaned surface and this ensures sufficient bond coat between the base substrate and the coating material. The thickness of the coating has been limited to 450 μm as increased thickness duly reduces the amount of air inducted in to the cylinder and this tends to decrease the volumetric efficiency of the engine, affecting the engine performance and emission.

3.2. After treatment process

In order to control NO_X emission from coated diesel engine, an additional SNCR circuit involving a tank with urea solution, 3 way control valve, small pump and flow pipes, was devised and fitted in the exhaust pipe, as show in Fig. 2. The urea solution was prepared by mixing 30% of urea with 70% of water, widely recognized composition for urea based SCR systems [15], and was placed overhead in the tank. Further, the urea solution was sprayed into the exhaust manifold and the quantity of injection was controlled by maintaining adequate pressure in the flow lines through the pump and control valve assembly. In this study, urea was directly sprayed into the exhaust gases without the requirement of any catalyst and hence the name, non-catalytic SCR system. Typically, a catalytic converter was not preferred along with the SNCR system, given that the coated engine is reported to have decreased other emissions such as CO and HC due to better combustion. Notably, this SNCR assembly was implemented only for coated engine and the emission results are compared with uncoated engine without SNCR. The selection of SNCR system to reduce NO_X emission than other strategies like EGR or retardation of injection timing is because of the fact that it does not compromises the engine performance, as modifications are only dealt in the tail pipe of the engine. Further, according to the reports of Casapu et al. [24], urea – SNCR system is more amenable for stationary diesel engine, like the one used in the current study, than light commercial vehicles in face of complexity and large dimensions of the system. Therefore, the selection of urea – SNCR system for the current study was reasonable.

Fig. 3. Engine components coated with PSZ (partially stabilized zirconia).

4. Results and discussion

Before appraising the effect of TBC on engine performance, it is worthwhile to analyze its impact on combustion process. In this connection, the variation of heat release rate and in-cylinder pressure for diesel, B25 and B50 in coated and uncoated engine, at full load condition, have been shown in Fig. 4a–c, respectively. It can be seen from the figures that for all the tested fuels, both the peak heat release rate and in-cylinder pressure of the coated engine are higher than that of uncoated engine due to the fact that heat lost were reduced in a coated engine. These results are in consonance with the results of Rajendra Prasath et al. [25], wherein, an improvement in in-cylinder pressure of around 3 bar has been reported for coated engine over normal diesel engine when fueled by Jatropha methyl ester. Furthermore, by comparing Fig. 4a and c, it could be noted that the peak heat release rate for B50 is lower than diesel both in coated as well as uncoated engine; mainly due to its lower calorific value. Another reason is the shorter ignition delay of KME on account of its higher cetane number, which is in agreement with the reports of Sarin [26]. Conceptually, the early start of combustion, accompanied by poor evaporation of KME, has yielded less amount of prepared fuel for premixed combustion, contributing to reduced peak heat release rate for B50.

The performance parameters such as BTE and BSFC have been analyzed to appreciate the effect of TBC on engine performance. For uncoated engine, BSFC was noticed to be increased with the increase of KME in the blend ratio, as seen from Fig. 5. This trend could be explained by the distinct property of KME, i.e. lower calorific value than diesel, which demands larger quantity of fuel to produce the required power output, resulting in higher BSFC. Similar reports on increase in BSFC for various biodiesel have also attributed lower calorific value of biodiesel as the prime reason for the reported occurrence [27,28]. However, for coated engine, the heat trapped inside the engine cylinder and the inherent presence of oxygen within the fuel have promoted better combustion for B25 and B50 and thereby, lowering the BSFC. Similar such conclusion had been drawn by Hazar [10], when testing canola methyl ester in a low heat loss diesel engine.

In general, the presence of oxygen within the renewable biodiesel promotes better oxidation of hydrocarbon [29], resulting in increased BTE. However, higher viscosity and lower calorific value of B50 caused a slight decline in efficiency compared to diesel and B25 in an uncoated engine. On the other hand, in a coated engine, the BTE of the engine, as shown in Fig. 6, gives a clear picture of improvement in engine performance for B50 as the heat loss to the surrounding has been minimized by the insulation of engine components. This reduced heat loss not only increases the energy available, but also improves the combustion process, enhancing the power output of the engine. As a result, an obvious higher efficiency has been achieved for all test fuels in coated engine. Remarkably, BTE was increased by 9% for B50 in a coated engine than in uncoated engine at full load condition. In the past, improvement in BTE of a coated diesel engine fueled by sunflower oil biodiesel was reported by Hasimoglu et al. [30], which is in concordance with the improved efficiency for B50.

The major emissions such as CO, HC, smoke and NO_X for diesel, B25 and B50 in coated and uncoated engine have been measured and analyzed. In light of higher viscosity, the combustion is incomplete for B50 in uncoated engine, resulting in higher CO and HC emission than diesel, which are shown in Figs. 7 and 8, respectively. However, B25 showed comparable CO and HC emission with diesel, as its viscosity is not much higher and further, the presence of oxygen within the fuel could have promoted oxidation of CO and HC. In general, many experimental investigation have shown more active combustion of biodiesel, due to the inherent possession of oxygen within its molecular structure, resulting in reduced CO

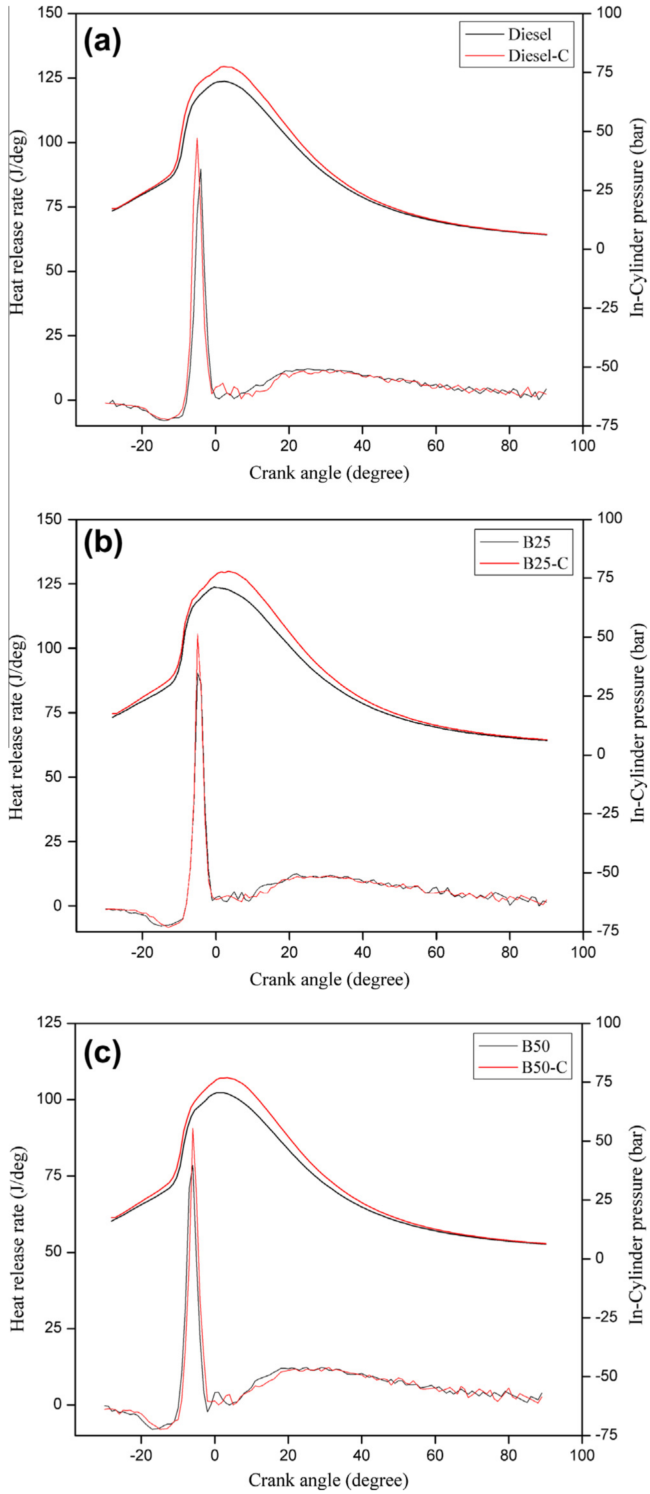

Fig. 4. In-cylinder pressure and heat release rate comparison for (a) diesel (b) B25 (c) B50 in coated (–C) and uncoated engine at full load condition.

and HC emission [31–33]. Nonetheless, there are also contradictions to the above said fact as the higher viscosity and boiling point of biodiesel affects the combustion process [34,35]. This is why B50 is reported to have shown higher HC and CO emission than diesel in uncoated engine.

It is very interesting to compare the CO and HC emission from coated engine and uncoated engine, and analyze the impact of coating on engine out emissions. Apparently, all the blend fuels

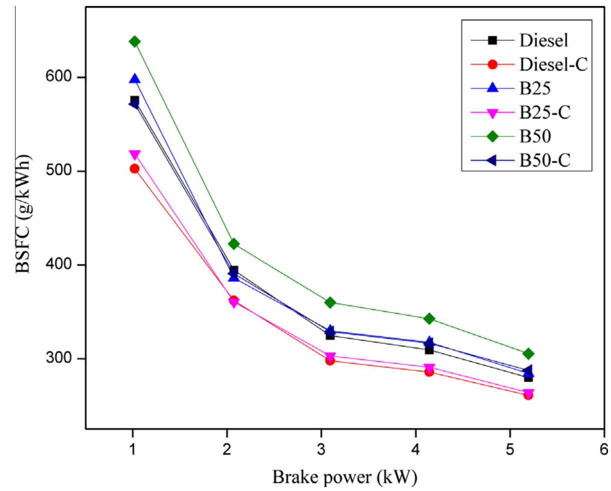

Fig. 5. Variation of BSFC (brake specific fuel consumption) for various blend fuels in coated (–C) and uncoated engine.

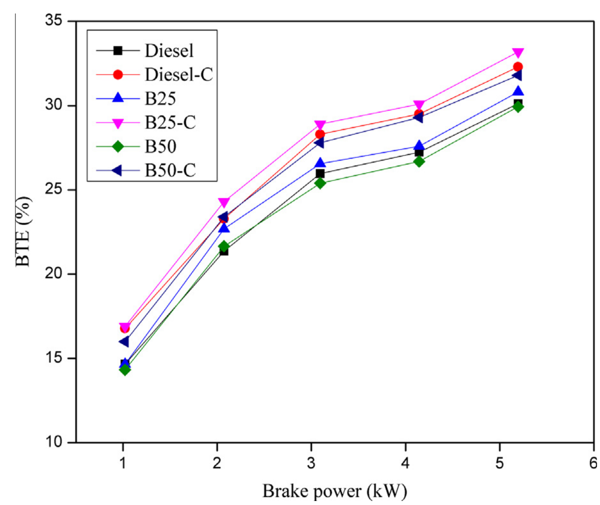

Fig. 6. Variation of BTE (brake thermal efficiency) for various blend fuels in coated (–C) and uncoated engine.

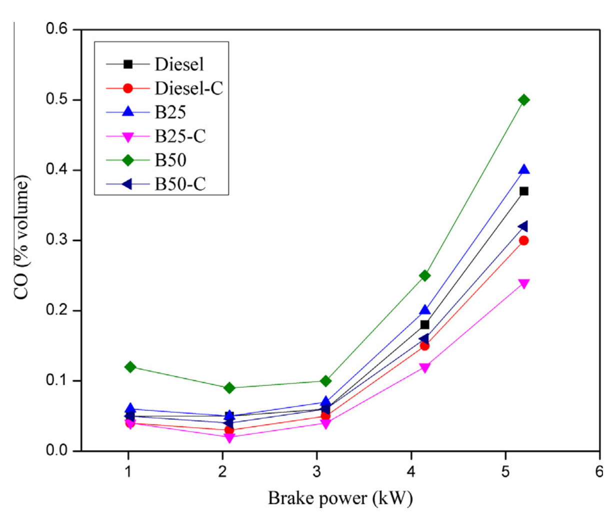

Fig. 7. Variation of CO (carbon monoxide) emission for various blend fuels in coated (–C) and uncoated engine.

showed decreased CO and HC emission in coated engine when compared with uncoated engine. This decrease can be judged based on the expected increase in in-cylinder temperature, due to the reduced heat losses to the coolant, in coated engine. The increase in temperature is believed to promote the oxidation of CO to CO_2, thereby reducing the CO emission by 40% for B50 in coated engine than that in uncoated engine. The same is the case for HC emission, with B50 in coated engine showing 35.3% reduction in HC emission than that in uncoated engine, perhaps slightly better than diesel too. Similar such reductions in HC and CO emission were also noted by Hazar [11] and MohamedMusthafa et al. [12], when using cotton and pongamia methyl ester in a coated diesel engine, complying with the findings of the current study. Categorically, it has been reported that SCR systems reduces HC and NO_X emissions, while the CO emission increases [36]. On the contrary, in the current study, an appreciable increase in CO emission has not been envisaged for B25 and B50 in coated engine with SNCR. This is because of the profound impact of coating, utilization the heat energy effectively in accomplishing more complete combustion within the combustion chamber itself.

In general, when biodiesel is being utilized as an alternate fuel for diesel engine, the NO_X emission is reported to be increased due to the inborn oxygen within fuel, fuel injection advance and other features pertaining to fuel chemistry [37]. However, as opposed to this, few researchers consider that the lower peak heat release rate, caused by lower calorific value and higher cetane number of biodiesel, reduces the in-cylinder temperature so as to impede the formation of NO_X [38]. Incidentally, the latter assertion, lower peak heat release rate to reduce NO_X emission, has happened in the present study for B50 with uncoated diesel engine, as seen from Fig. 9. The reasons for this are explained as follows: due to the higher viscosity and lower boiling point of KME, the atomization and evaporation of it are believed to be affected and therefore, the quantity of well mixed fuel available for combustion is reduced. Following this, the lower cetane number of KME advances the combustion process and with the reduced quantity of fuel being available for combustion, coupled by the lower calorific value of KME, the magnitude of peak heat release rate is decreased and this turn reduces the in-cylinder temperature to decrease the NO_X emission for B50.

On the other hand, it is widely noted that coated engine tends to increase the in-cylinder temperature and this together with the presence of oxygen within the biodiesel would cause an increase in NO_X emission. As high temperature and presence of surplus oxygen are reported to be crucial in the formation of NO_X [39,40]. Substantially, Aydin [14] and Iscan and Aydın [13], demonstrated an increase in NO_X emission when using sunflower oil and waste corn oil in a coated engine, perhaps for the same reason as noted above. In the event of increasing the performance of a diesel engine fueled by KME-diesel blends through coating of engine components, similar phenomenon is believed to arise. To avert the expected increase in NO_X emission for the blend fuels in the current experimental study using PSZ coated engine, urea based SNCR system, which is regarded as an effective after treatment technique [41], has been fitted in the exhaust pipe. With the SNCR fitted coated engine, the NO_X emissions for B25 and B50 were successfully reduced, as shown in Fig. 9. The ideology behind NO_X reduction with urea – SNCR system is: when urea is sprayed in the exhaust pipe, it gets decomposed and hydrolyzed into ammonia (NH_3), while the formed ammonia then reacts with NO and NO_2 and breaks it down to N_2 and H_2O. Consequently, NO_X emission for B50 in coated engine with SNCR has been reduced by 13.4% than that in uncoated engine. In parallel with these conclusions, Xu et al. [42] and Liu et al. [43] had already reported a drastic reduction in NO_X emission by implementing urea based NO_X reduction system. However, when compared to diesel, the NO_X emission for B50 was noticed to be slightly lower due to deterrence in combustion and the subsequent reduction in in-cylinder temperature, caused by the higher viscosity of KME and for the other reasons with the early start of combustion as explained above. It could be pointed out that the NO_X emission for lower blend, B25, was shown to be higher than diesel, as the fuel properties of it are in par with diesel.

There always exists a tradeoff between NO_X and smoke emission in a diesel engine fueled by any kind of fuel. However, in our case, this tradeoff has been refrained with the realization of coating and implementation of urea – SNCR system, as both NO_X and smoke are simultaneously reduced for B50. Notably, a 21.4% decrease in smoke emission for B50 in coated engine than that in uncoated engine, as noted from Fig. 10, has been realized. Characteristically, the soot precursors formed in the fuel rich zones of spray are oxidized by the oxygen from KME and this is further ameliorated by the enhanced combustion temperature, following the prevention of heat loss through coating. To back this up, Di et al. [44], in their study using oxygenated fuel (ethanol) as substitute for diesel, acceded to the profound oxidation of fuel and reported effective reduction in smoke emission. In general, when the premixed combustion is more pronounced, the soot formations

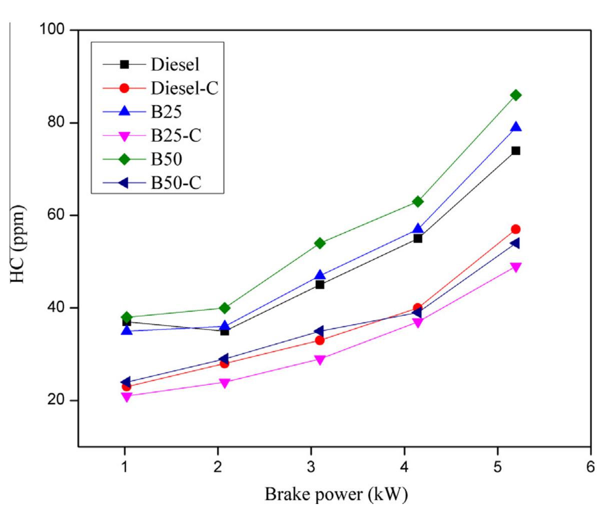

Fig. 8. Variation of HC (hydrocarbon) emission for various blend fuels in coated (–C) and uncoated engine.

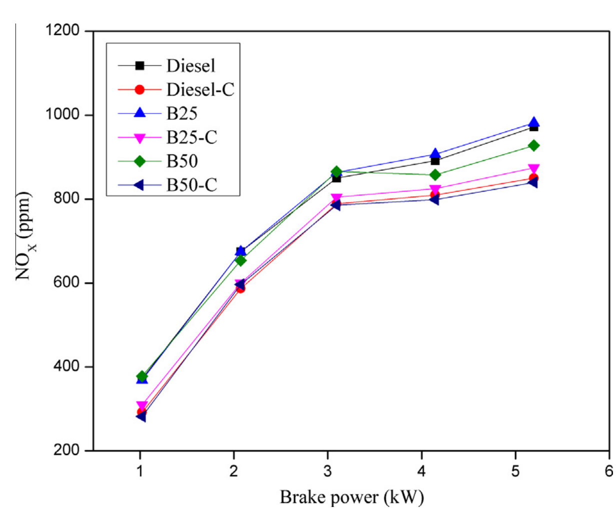

Fig. 9. Variation of NO_X (oxides of nitrogen) emission for various blend fuels in coated (–C) and uncoated engine.

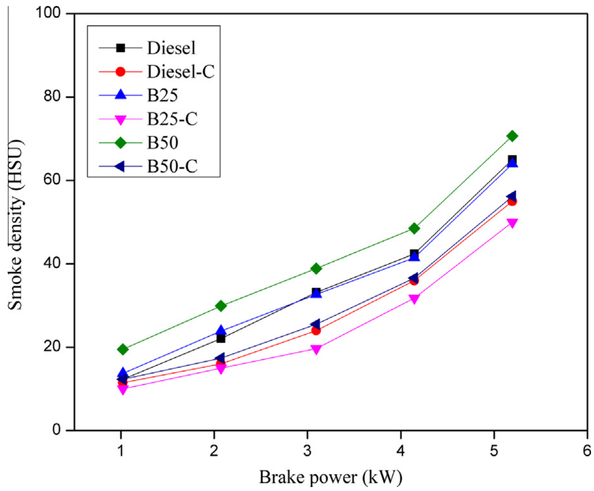

Fig. 10. Variation of smoke emission for various blend fuels in coated (–C) and uncoated engine.

are reduced as the amount of fuel being burnt in diffusion controlled combustion is reduced [45]. In our case, since premixed combustion is more pronounced for B50 in a coated engine, as seen from Fig. 4, the smoke emission are noted to be reduced than that in an uncoated engine.

5. Conclusion

The first objective of this investigation was to improve the performance of a diesel engine fuelled by biodiesel by coating the engine components using PSZ, a commensurate insulating material. Secondly, the increased NO_X emissions from the coated diesel engine, due to rise in temperature inside the combustion chamber, has been identified and efforts were taken to reduce it by implementing urea – SNCR system in the exhaust pipe. Further, this study has also thrived to duly utilize kapok seed oil, an underutilized bio oil, to synthesize biodiesel (KME) and experimentally investigate the engine characteristics in a coated diesel engine with SNCR. From the experimental investigation, the performance and combustion characteristics are found to be improved for the blend fuels in coated engine, with a 9% increase in BTE for B50 in coated engine than uncoated engine at full load condition. Further, the major emissions from the coated engine such as HC, CO and smoke for B50 were found to be reduced by 35.3%, 40% and 21.4%, respectively, than uncoated engine. In addition, with the incorporation of urea – SNCR systems, the NO_X emission was also reduced by 13.4% than uncoated engine. Previously, many research studies on coated diesel engine with biodiesel, categorically reported better engine performance and reduction of HC, CO and smoke emission at the expense of higher NO_X emission. However, distinctly, this study has duly noticed the problem of higher NO_X emission with coated engine fueled by biodiesel and subsequently, an effective after treatment technique in the likes of SNCR was incorporated to reduce the rampant impact of NO_X emission on atmosphere, implicating much greener environment.

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